H_2 molecules and cold clouds in cooling flow clusters†

By L. Grenacher, Ph. Jetzer, D. Puy

[1]Paul Scherrer Institute, Laboratory for Astrophysics, Villigen (Switzerland)

[2]Institute of Theoretical Physics, University of Zurich (Switzerland)

1. Introduction

Around the epoch of recombination atomic hydrogen is the most important chemical species and leads by adiabatic cooling of the universe to the formation of molecular hydrogen H_2 (Puy et al. 1993, Puy & Signore 1999). The actual H_2 content is very uncertain and estimated only indirectly. The important recent observation of the lowest pure rotational lines of H_2 in the spiral galaxy NGC 891 (Valentijn & Van der Werf 1999) gives a direct indication of relatively warm (T=150-230 K) molecular clouds in the disk in addition to a massive cooler (80-90 K) component in the outer regions.

In clusters of galaxies X-ray measurements show an excess absorption below ~ 1 keV compared to a best fit bremsstrahlung model, which is interpreted as due to the presence of cold molecular clouds (White et al. 1991).

In a scenario with successive fragmentation of these clouds we calculate the molecular rotational line cooling due to HD- and H_2-molecules and determine their minimum temperature achievable in equilibrium with the exterior bremsstrahlung of the hot intracluster gas.

2. Molecular cooling

The abundance η_{HD} of the HD molecule is considered to be primordial:

$$\eta_{HD} \simeq 7 \times 10^{-5}, \text{ Signore} \,\&\, \text{Puy 1999.}$$

The quadrupole transitions of H_2 are supposed to follow an ortho/para ratio of 1, its first excited state is at 512 K. Although this cooling is less efficient than the cooling due to HD, H_2 is more abundant and we expect the H_2 cooling to be more important than the HD cooling in the temperature region above ~ 100 K and in the density region of 10^4 cm^{-3}.

Considering only the transition between the ground state and the first rotational level, the molecular cooling can be calculated analytically (Puy, Grenacher and Jetzer 1999). In the case of H_2-clouds temperatures as mentioned above, the higher excitation levels turn out to be significant even if they are still very weakly populated.

In Figure 1 we show for the total cooling $\Lambda_{H_2} + \Lambda_{HD}$ the relative importance of the cooling agents H_2 and HD

$$\alpha_{H_2} = \frac{\Lambda_{H_2}}{\Lambda_{H_2} + \Lambda_{HD}}$$

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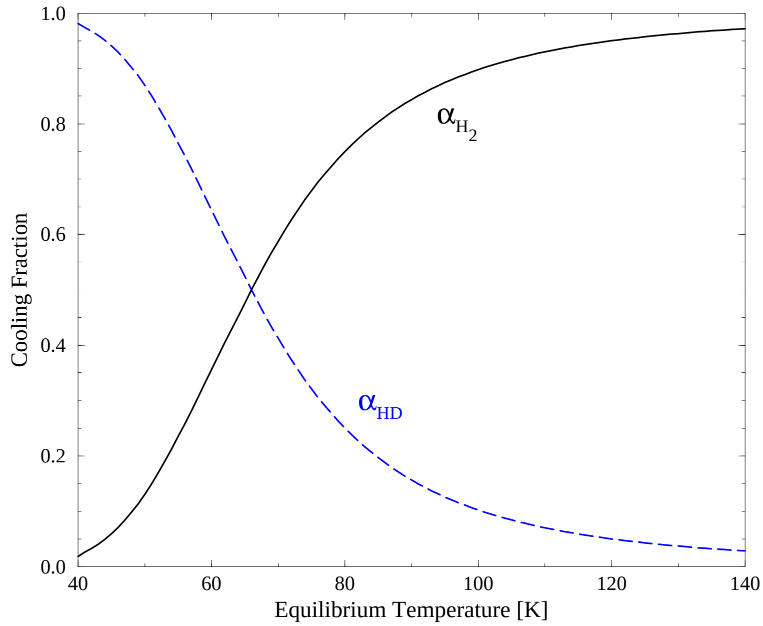

FIGURE 1. Relative importance of the different cooling agents H_2, $\alpha_{H_2} = \Lambda_{H_2}/(\Lambda_{H_2} + \Lambda_{HD})$ and HD, $\alpha_{HD} = \Lambda_{HD}/(\Lambda_{H_2} + \Lambda_{HD})$.

$$\alpha_{HD} = \frac{\Lambda_{HD}}{\Lambda_{H_2} + \Lambda_{HD}} \ .$$

We can see clearly, that H_2 becomes the most important cooling agent above $\sim$ 70 K.

3. Thermal equilibrium

The most important heat source for molecular clouds in cooling flows is the X-ray bremsstrahlung emitted by the hot intracluster gas. In the successive fragmentation scenario this radiation is shielded by the presence of an attenuating column density in the outher parts of the clouds, which we take into account by the attenuation factor, τ, following O'Dea et al. (1994).
The balance between heating and cooling in the cluster environment leads to a thermal equilibrium inside the cooling flow region of the clusters. The escape probability for this molecular emission is close to 1. We investigate the coldest equilibrium achievable inside the cooling flow region.

4. Discussion

We consider small clouds ($\sim$ 10 AU) with an H_2 density of 10^4 cm^{-3}, attenuated by $\tau = 0.01$. The X-ray heating ($\Gamma_X(r) \propto r^{-3}$) is of course more important in the cluster center and low equilibrium temperatures are achieved at large distances from the cluster center. Nevertheless, the fact that the cold clouds are located in the cooling flow region implies that the distance must be below the cooling radius. In this context we have calculated the equilibrium temperature of the molecular clouds located at the cooling radius. The table gives these equilibrium temperatures T_{clump} for different clusters of galaxies.

Cluster	$\mathbf{T_{clump}}$ (in K)	$\mathbf{r_{cool}}$ (in kpc)	$\mathbf{T_{Kev}}$ (in keV)
Centaurus	153	87	2.1
Hydra A	107	162	4.5
PKS 0745-191	92	214	8.6
Abell 262	119	67	2.5
Abell 426	83	145	6.3
Abell 478	228	240	7.1
Abell 496	58	138	4.8
Abell 539	133	34	3.4
Abell 576	102	69	2.9
Abell 1060	102	68	3.3
Abell 1367	80	40	4.1
Abell 1795	136	181	5.3
Abell 2052	96	140	3.4
Abell 2151	256	146	2.9
Abell 2159	128	119	4.5

TABLE 1. The equilibrium temperature T_{clump} at the cooling radius r_{cool} for the cluster temperature T_{keV} are shown for different cluster of galaxies.

In the region of the cooling flow, we find that an equilibrium is possible at low temperature (below 200 K) due to H_2 cooling.
Whether the cloud can be cooled down to $\sim$ 70 K, where HD dominates, depends on various parameters, such as the cluster temperature T_{keV}, the attenuation factor τ, the cooling radius r_{cool} and other characteristics of the hot intracluster gas.
The detection of these H_2 molecules is difficult, because the first rotational level, acccessible only through a quadrupolar transition, is more than 500 K above the fundamental. The study of CO-H_2 ratios can give some insight, because the CO molecules are excited by collisions with H_2, and should be a tracer of cold H_2 clouds (Grenacher et al. 1999). In this context cold H_2-clouds could be an interesting possibility of baryonic dark matter (Combes 1999). The FUSE satellite will certainly give clarification on this problem.

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